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ROADSIDE SAFETY AUDITS

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ABSTRACT

Roadside adjustment has a remarkable effect on road safety. An effective strategy for roadside safety improvement may be based on safety audits, both of detailed design and of existing roads.

Accident data analyses do not always allow to locate the roadside safety problems because usually roadside defects have limited extension and may not have influenced in meaningful way the accident rates. However, a roadside punctual analysis aimed at identifying the accident potential and safety performance may be an effective approach with low costs and great benefits.

A roadside safety audit of some Italian highways has underlined a lot of safety problems which, in most cases, are of repetitive nature and may be eliminated or mitigated with low cost measures.

Main roadside safety problems have been classified and detailed checklists have been developed. The main dangerous factors singled out relate to the safety barriers structural adequacy (low containment capacity in sites with high dangers, behavior excessively rigid towards the passenger cars), to the safety barriers functional adequacy (inadequate longitudinal extension for the complete protection of the obstacles, inadequate distance from the protected obstacles, installation conditions not suitable, etc.), to the safety barriers transitions and terminals, other than to the presence of unprotected obstacles inside the clear zone.

INTRODUCTION

About one third of road fatalities result from single vehicle run off the road accidents. To reduce this toll many measures are possible: remove the hazard, relocate the hazard, make the hazard forgiving and shield the hazard with road restraint systems. The top priorities (1) are to remove or relocate roadside hazards so as to provide a clear zone along the roadside that provides errant vehicles an opportunity to recover and return to travelway or to come to a controlled and safe stop. For situations in which fixed objects have to be located in the clear zone, such as luminaries and sign supports that have to be placed close to the travelway, these fixed objects may be designed to be forgiving by making them break away or yield on impact to minimize the potential for injury to the vehicle occupants. In situations in which the above countermeasures are not applicable, road restraint systems, as longitudinal safety barriers and crash cushions (2-8), may be installed.

Roadside adjustment, as new design, is aimed at improving road safety. A significant contribution for roadside safety improvement may be given from safety audit, which is defined as (9):

"a formal examination of an existing or future road or traffic project, or any project which interacts with road users, in which an independent, qualified examiner reports on the project's accident potential and safety performance" ;

or as (10);

"*a means of checking the design, implementation and operation of road projects against a set of safety principles as a means of accident prevention and treatment*".

Road safety audits relate to all aspect of projects and existing roads affecting safety. They can provide increased safety in two ways (11):

1. by removing preventable accident-producing elements at the planning and design stage; or
2. by mitigating the effects of remaining or existing problems by the inclusion of suitable crash-reduction features, such as road restraint systems.

Specific roadside audits increase safety by mitigating the effects of remaining or existing problems. They may be carried out both in the case of new designs and of roadside adjustment, which will be needed in the next years in great part of the EU road network, due to the publication of the new standards EN 1317 (2-7).

Roadside safety audits may be useful in the following phases:

- Detailed design, aimed at identifying if roadside safety is properly taken into account in the design process;
- Pre-opening, aimed at identifying constructions aspects and restraint systems installation conditions detrimental to road safety;
- Existing roads, aimed at identifying roadside safety deficiencies and adjustment priorities.

Actors involved in the process are the *client*, the *designer* and the *auditor*:

- The client should be responsible for ensuring that clear terms of reference are laid down to cover the whole range and scope of audit, and for commissioning audits at appropriate stages;
- The designer should be responsible for initiating the safety audit process for each scheme, and responding to the audit;
- Auditor should identify potential safety problems and provide constructive recommendations as to how any potential design difficulties can be resolved.

In the paper recommendations on the auditor's task are given.

DETAILED DESIGN

In the detailed design, the selection of road restraint systems performance classes and location, within the construction details, are carried out. Some of the main safety aspects to audit are reported below (see table 1).

Unprotected obstacles

One of the greater hazard for vehicle leaving the road is the crash against fixed objects: luminaries and signs supports, trees, not attraversabile drainage, bridge abutments and piers, rigid obstacles.

The auditor should check the presence of unprotected hazards within the clear zone. The clear zone distance depends on many factors (12-13), as traffic speed (design speed or 85^{th} percentile speed) and volume, horizontal curvature, lateral slopes and crash severity.

Median openings require special attention for safety auditors. If mobile protections are not present, it is possible that encroaching vehicles have frontal crash with opposite traffic and the safety barriers terminals may constitute an hazard. If mobile protections are present, containment level and dangerous singular points have to be checked.

Safety barriers containment level adequacy

Safety auditor has to assess if properly safety barriers performance classes have been selected. Main factors to be taken into account by the auditor are kind and location of hazards, traffic volume and composition, type and geometrical features (horizontal curvature, longitudinal grade, number of lanes, lanes width, shoulder width, etc.) of the road.

Safety auditor should also check the methods for the selection of performance classes used by the designer. Incremental benefit/cost analysis has been widely accepted as the most appropriate method for evaluating safety alternatives (14-16).

Barrier transitions

Safety barriers of different cross section or different lateral stiffness have to be connected by a transition element. The purpose of a transition is to provide a gradual change between the two barriers, to prevent the hazards of an abrupt transition (5). Improper transitions may constitute a great hazard, especially when flexible and rigid barriers are connected (e.g., steel and concrete safety barriers or roadside and bridge railings). To date, only few transitions have been successfully crash tested. Therefore, it is worthwhile than auditor carefully verifies transitions design.

Barrier terminals

A terminal is the beginning or the end of a safety barrier. A terminal may function by decelerating a vehicle to a safe stop within a relatively short distance, permitting controlled penetration of the vehicle behind the device, containing and redirecting the vehicle or by a combination of the three behaviors. Furthermore a terminal may provide an anchorage for the barrier system.

Improper terminals may give rise to penetration of safety barriers elements into to colliding vehicle and/or dangerous decelerations for the vehicle occupants.

While in USA many terminals fulfil the NCHRP requirements (8), in EU only few terminals have been successfully crash tested.

Restraint systems installation conditions

Field installation conditions of restraint systems may be quite different from crash test installation conditions. The auditor has to verify the consistency of installation conditions with safety barriers performances.

Auditor should check that dynamic deflection of restraint system, that is the maximum lateral dynamic displacement of the side facing the traffic of the restraint system, is lower than the distance between barrier and protected obstacles. If this condition is not verified the safety barrier absorbs only part of the vehicle's kinetic energy, while the remainder would be dissipated in the crash against the obstacle, involving damages to the vehicle's occupants.

For barrier installed on embankments, the distance between safety barrier and the embankment edge should be sufficient to avoid that the vehicles wheels go on the scarp and to assure adequate contrast to poles.

When median barrier are installed on horizontal curves, the different level of the two

carriageway may prevent the correct barriers behavior.

Interaction between safety barriers and other objects

Auditor has to verify that the interaction of the safety barriers with other elements, as road traffic noise reducing devices, light poles and drainage, don't involve safety problems.

PRE-OPENING

Many aspects of roadside design require safety audit before opening the road to the traffic (see table 2). Especially, in the pre-opening phase it is possible to check unprotected obstacles, hazards not analyzed in the design phase and the road restraint systems installation conditions.

Unprotected obstacles

Safety auditor has to verify that there are not unidentified hazards within the clear zone.

Safety barriers containment level adequacy

Safety auditor has to verify if there are specific hazards (e.g. schools, hospitals) that may require safety barriers with higher containment level.

Terminals and transitions

Safety auditor has to verify proper construction of terminals and transitions, which may be very dangerous features.

Restraint systems installation conditions

The auditor has to verify both the proper application of the design specifications and the effectiveness of the design solutions.

Especially, auditor should check the distance between safety barrier and obstacles, that may be lower that design specifications due to inaccurate plotting.

Safety barriers anchorages may be dangerous: uncompressed ground, poles too close to embankment edge, drainages or other elements which prevent correct barriers behaviors.

Interaction between safety barriers and other objects

Auditor has to verify that the interaction of the safety barriers with other elements, as road traffic noise reducing devices, light poles and drainage, don't involve safety problems.

Table 1 Detailed design checklist

Item	Issues to be considered
Unprotected obstacles	Are there non break-away and unprotected light poles to distance from carriageway lower than the clear zone distance? Are there trees to distance from carriageway lower than the clear zone distance? Are there unprotected not attraversabile drainage drainage? Are there unprotected bridge abutments and piers? Are there unprotected rigid obstacles to distance from carriageway lower than the clear zone distance? Are median openings properly designed? Is spacing between median crossovers appropriate?
Safety barriers containment level adequacy	Have incremental benefit/cost analysis been used for the selection of the safety barriers containment level? Are the containment levels of the safety barriers adequate to the severity of the hazards? Are the containment levels of the safety barriers adequate to the traffic volume and composition?
Barrier transitions	Are barriers with different containment level connected with transitions that assure gradual change in the system performance? Are barriers with different stiffness connected with transitions that assure gradual change in the system stiffness?
Barrier terminals	Are the terminals an hazard for colliding vehicles? Are dangerous terminals located in an area with low collision probability? Do the terminals provide adequate anchorage to the safety barriers?
Restraint systems installation conditions	Is the distance between barrier and obstacle lower than barrier's dynamic deflection? Is the distance between barrier and embankment edge sufficient to avoid that the vehicles wheels go on the scarp? Is the distance between barrier and embankment edge sufficient to adequate contrast to poles? Have been designed measures to assure correct behavior of safety barriers on embankments? Is longitudinal extension of safety barrier adequate to assure the structural resistance needed for his correct behavior? Is longitudinal extension of safety barrier adequate to assure protection from hazards? Are installation condition adequate to assure acceptable risk indexes for car occupants? Do median barriers on horizontal curves properly work?
Interaction between safety barriers and other objects	Are there elements which prevent correct barrier behavior? Are there measures to assure proper interaction between safety barriers and noise reducing devices? Do lighting poles prevent correct behavior of safety barriers? Do drainage prevent correct behavior of safety barriers?

Table 2 Pre-opening checklist

Item	Issues to be considered
Unprotected obstacles	Are there unprotected obstacles within the clear zone? Are median openings properly protected?
Safety barriers containment level adequacy	Are the containment levels of the safety barriers adequate to the hazards?
Barrier transitions	Do transitions between barriers assure gradual change in the system performance and stiffness?
Barrier terminals	Are the terminals an hazard for colliding vehicles? Are dangerous terminals located in an area with low collision probability? Do the terminals provide adequate anchorage to the safety barriers?
Restraint systems installation conditions	Is the distance between barrier and obstacle lower than barrier's dynamic deflection? Is the distance between barrier and embankment edge sufficient to avoid that the vehicles wheels go on the scarp? Is the distance between barrier and embankment edge sufficient to adequate contrast to poles? Have been done measures to assure correct behavior of safety barriers on embankments? Is the ground properly constipated? Is longitudinal extension of safety barrier adequate to assure the structural resistance needed for his correct behavior? Is longitudinal extension of safety barrier adequate to assure protection from hazards? Are installation condition adequate to assure acceptable risk indexes for car occupants? Do median barriers on horizontal curves properly work?
Interaction between safety barriers and other objects	Are there elements which prevent correct barrier behavior? Are there measures to assure proper interaction between safety barriers and noise reducing devices? Do lighting poles prevent correct behavior of safety barriers? Do drainage prevent correct behavior of safety barriers?

EXISTING ROADS

Roadside safety audit of existing road relates to both general and detailed aspects.

General aspects involve the evaluation of safety barriers performance classes on the whole network and are part of the global policy for road safety improvement and safety barriers adjustment. Acceptance of auditors recommendations involve a significant expenditure.

Detailed aspects involve the evaluation of local defects. Since these defects have limited extension, they may me overlooked by accident analysis and may not have influenced in meaningful way the accident rates. Instead, a roadside punctual analysis aimed at identifying the accident potential and safety performance may be an effective approach with low costs and great benefits.

Safety barriers containment level adequacy

Auditor should check if road restraint systems have been successfully crash tested.

If barriers have been crash tested, the auditor should assess if properly safety barriers performance classes have been selected. Main factors to be taken into account by the auditor are kind and location of hazards, traffic volume and composition, type and geometrical features (horizontal curvature, longitudinal grade, number of lanes, lanes width, shoulder width, etc.) of the road. Safety auditor should also check the methods for the selection of performance classes used by the designer.

If barriers have not been crash tested, the auditor should make a subjective evaluation of the performance classes of the safety barrier by comparing the features of the existing barriers with the features of the tested barriers. In some cases there is great evidence of the safety barriers upgrade need (see fig. 1). In other cases benefit/cost analysis and guidelines may assist auditor in the assessment.

FIGURE 1 Bridge rail with low containment level (height = 0.6 m) which needs upgrading.

Unprotected obstacles

In the existing roads there are a lot fixed objects within the clear zone: luminaries and signs supports, trees, not attraversabile drainage, bridge abutments and piers, rigid obstacles.

Usually checking presence of obstacle within clear zone is an easy task (see fig. 2). In more complex situations benefit/cost analysis and guidelines may assist auditor in the

assessment of the clear zone distance.

FIGURE 2 Bridge pier within the clear zone in a Motorway.

Terminals and transitions

Safety auditor has to verify behavior of terminals and transitions, which may be very dangerous features.

FIGURE 3 Improper transition between steel and concrete barriers.

Restraint systems installation conditions

Often, improper installation conditions prevent correct safety barriers behavior. Especially, auditor should check the distance between safety barrier and obstacles, that may be lower that safety barrier dynamic deflection (see fig. 4).

Safety barriers anchorages may be dangerous: uncompressed ground, poles too close to embankment edge, drainages or other elements which prevent correct barriers behaviors.

FIGURE 4 Distance between safety barrier and obstacle lower than barrier's dynamic deflection.

Interaction between safety barriers and other objects

Auditor has to verify that the interaction of the safety barriers with other elements, as road traffic noise reducing devices, light poles and drainage, don't involve safety problems.

Table 3 Existing roads checklist

Item	Issues to be considered
Safety barriers containment level adequacy	Have been the safety barriers successfully crash tested?
	Have suitable methods been used for the selection of safety barriers performance classes?
	Are the containment levels of the safety barriers adequate to the kind and location of the hazards?
	Are the containment levels of the safety barriers adequate to traffic volume and composition?
	Are the containment levels of the safety barriers adequate to the functional class and geometrical features of the road (horizontal curvature, longitudinal grade, number of lanes, lanes width, shoulder width, etc.)?
	If the safety barriers have not been crash tested, are their features adequate to the above said hazards?
Unprotected obstacles	Are there unprotected obstacles within the clear zone?
	Is spacing between median crossovers appropriate?
	Are median openings properly protected?
Barrier transitions	Have been the transitions successfully crash tested?
	Do transitions between barriers assure gradual change in the system performance and stiffness?
Barrier terminals	Have been the terminals successfully crash tested?
	Are the terminals an hazard for colliding vehicles?
	Are dangerous terminals located in an area with low collision probability?
	Do the terminals provide adequate anchorage to the safety barriers?
Restraint systems installation conditions	Is the distance between barrier and obstacle lower than barrier's dynamic deflection?
	Is the distance between barrier and embankment edge sufficient to avoid that the vehicles wheels go on the scarp?
	Is the distance between barrier and embankment edge sufficient to adequate contrast to poles?
	Have been done measures to assure correct behavior of safety barriers on embankments?
	Is the ground properly compressed?
	Is longitudinal extension of safety barrier adequate to assure the structural resistance needed for his correct behavior?
	Is longitudinal extension of safety barrier adequate to assure protection from hazards?
	Are installation condition adequate to assure acceptable risk indexes for car occupants?
	Do median barriers on horizontal curves properly work?
Interaction between safety barriers and other objects	Are there elements which prevent correct barrier behavior?
	Are there measures to assure proper interaction between safety barriers and noise reducing devices?
	Do lighting poles prevent correct behavior of safety barriers?
	Do drainage prevent correct behavior of safety barriers?

CONCLUSIONS

Roadside safety audit may be an effective methodology for road safety improvement.

A roadside safety audit of some Italian highways has underlined a lot of safety problems which, in most cases, are of repetitive nature and may be eliminated or mitigated with low cost measures.

Main roadside safety problems have been classified and detailed checklists have been developed. The main dangerous factors singled out relate to the safety barriers structural adequacy (low containment capacity in sites with high dangers, behavior excessively rigid towards the passenger cars), to the safety barriers functional adequacy (inadequate longitudinal extension for the complete protection of the obstacles, inadequate distance from the protected obstacles, installation conditions not suitable, etc.), to the safety barriers transitions and terminals, other than to the presence of unprotected obstacles inside the clear zone.

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